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TECHNIQUES FOR CATHODIC PROTECTION TESTING OVER AIRFIELD PAVEMENTS

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APRIL 1979

FINAL REPORT AUGUST 1977-JULY 1978

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CIVIL AND ENVIRONMENTAL
ENGINEERING DEVELOPMENT OFFICE
(AIR FORCE ENGINEERING AND SERVICES CENTER)
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This report summarizes the techniques developed for cathodic protection testing over airfield pavements. Tests results conclusively proved that the accuracy of all pipe-to-surface potential measurements taken over pavement surfaces are questionable. On concrete pavement it was found that potential readings differed from readings on adjacent soil by more than 100 millivolts. Potential readings over well sealed asphalt surfaces were not possible even when using high input impedance, electronic voltmeters. Potential readings over deteriorated asphalt were possible but the accuracy was poor. Accurate potential

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measurements over pavement surfaces can be made only if the reference electrode contacts the surface beneath the pavement. This report recommends a procedure for easily penetrating the pavement surface and installing a pavement insert through which a modified reference electrode may be inserted.

PREFACE

This report was prepared for the Air Force Civil and Environmental Engineering Development Office (CEEDO) under Job Order Number 21045C01. Report summarizes work done between August 1977 and July 1978 by the Harco Corporation under Phase I of Contract Number F08635-77-C-0248.

The CEEDO Technical Monitor was Major Roger J. Girard and the Harco Principal Investigator was Mr. Bernard Husock.

Effective 1 March 1979 CEEDO was inactivated and became the Engineering and Services Laboratory (ESL) a Directorate of the Air Force Engineering and Services Center located on Tyndall AFB Florida 32403.

This report has been reviewed by the Information Office (IO) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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SECTION I
INTRODUCTION

The Problem

The Air Force has recognized that cathodic protection is an effective and economic method for preventing corrosion of underground metallic structures such as pipe lines and tanks. In order to determine whether cathodic protection systems are functioning effectively, it is acknowledged that it is necessary to take electrical measurements periodically. These electrical measurements are the structure-to-electrolyte potentials taken using a reference electrode placed in the soil or water and a voltmeter as shown schematically in Figure 1.

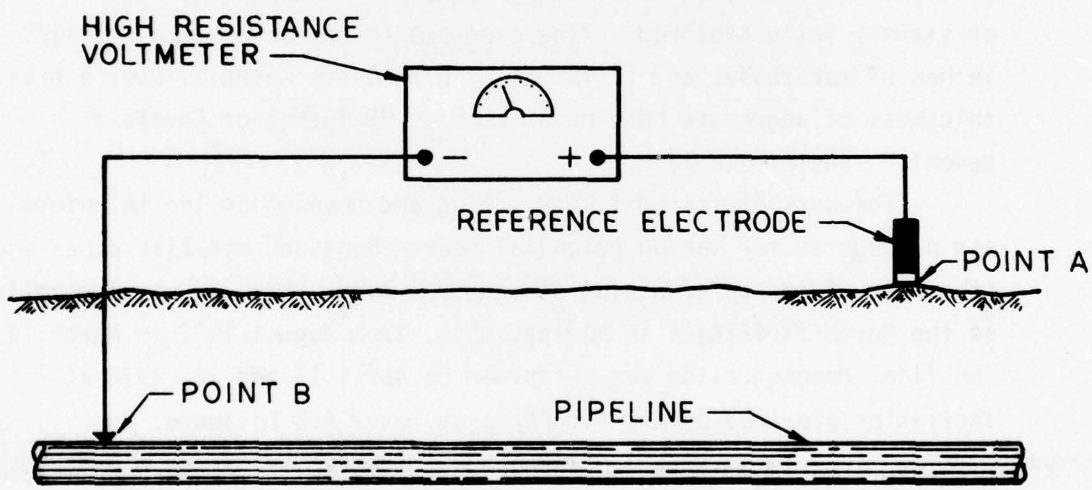

Figure 1. Pipe-to-Soil Potential

Because the use of potential measurements is the only practical method for determining whether a cathodic protection system is operating correctly, it is important that the measurements be accurate and correct.

If it is assumed that the instrument is capable of accurately measuring the voltage across terminals, the correctness of the measurements then depends upon the IR drops in the remainder of the measuring circuit. The IR drops which contribute most to the introduction of error result from resistance in:

1. the contact to the structure, point B in Figure 1
2. the contact between the reference electrode and the electrolyte - point A in Figure 1

The influence of resistance in the contact to the structure can be reduced to a negligible value by the use of test leads connected to the structure. But where underground structures are situated under paved areas, such as is the case in POL systems at Air Force bases, the problems introduced in obtaining a correct potential have not been previously fully explored. "These pavements may be as much as 2-1/2 inches of tar-rubber and 12 inches of bituminous material over a great thickness of aggregate base or as much as 28 inches of Portland cement." (Reference 1)

The work performed in evaluating and developing the techniques and procedures for taking potential measurements on metallic pipes and other structures under paving as required under Phase I, was accomplished at the Harco facilities in Medina, Ohio, from August 1977 to March 1978. The final demonstration was performed on April 11 and 12, 1978 at facilities provided by the Air Force at Dover AFB Delaware.

Literature Review

Despite the self-evident nature of the problems inherent in trying to obtain correct potential measurements on structures under paving, there is very little in the standard texts and literature on cathodic protection that mentions these problems. While some of the early Air Force (Reference 2) and other government manuals (Reference 3) show no particular awareness of the problem, the 1975 Air Force

publication by West and Lewicki (Reference 4) does make mention of the "stubby" reference electrode and that its use "improves contact-to-electrolyte where poor contact is anticipated or when readings are taken through concrete or in frozen ground." Although texts by Parker (Reference 5) and Applegate (Reference 6) indicate that the need for high resistance instruments is a result of resistance in the external circuit, and the possible percent error effected soil contact resistance is demonstrated by Applegate, there is no specific procedure recommended for coping with paved areas. The British Code of Practice for Cathodic Protection (Reference 7) discusses the need for a low resistance contact between the reference electrode and earth. It notes that in paving "it may be necessary to bury the reference electrode in a pile of moist soil or sand placed over the cracks between paving stones." It further states that "effective contact should be confirmed by varying the instrument scale range." The use of varying the instrument scale range to determine the effect of the contact resistance will be discussed later in this report. A recent publication by Myers and Aimone (Reference 8) mentions that "errors in measuring structure-to-electrolyte potentials under areas covered with concrete can be minimized by wetting the region and using a larger surface area reference electrode having a flat porous plug. When possible, the electrode should be positioned over a crack in the concrete."

Research Methodology

Although the existing literature does not make explicit statements regarding the validity of potential measurements taken on paving, there is the implication that if the reference electrode contact is sufficient to produce what appears to be a reasonably correct reading, then the use of high resistance instruments and particularly potentiometer-voltmeter circuits assures the validity of the measurement. We could find little in the literature giving any indication that the paving itself exerts any significant influence which distorts the reading or produces aberrant results.

Thus, even though there was little concern about any direct influences from the paving, there were doubts as to whether presently available measurement techniques could produce consistently correct readings through the type of paving to be encountered at Air Force facilities. Therefore, there is a definite need to develop techniques which the corrosion technician can conveniently and easily use to obtain correct readings. In order to accomplish this, four fundamental avenues of approach were explored in our research. These are:

1 Improve existing techniques by developing instrumentation and reference electrodes to take readings directly through the paving.

2 Develop tools and procedures for penetrating directly through the paving to the underlying soil.

3 Develop tools and procedures for penetrating horizontally under paved areas from adjacent unpaved areas.

4 Develop mathematical relationships which can be used to calculate the true potentials in paved area from the readings obtained in neighboring unpaved areas.

SECTION II
DISCUSSION OF METHODOLOGY

Improve Existing Techniques

This portion of the work centered on investigating whether recently developed "state-of-the-art" instruments are more effective than presently available instruments for measuring through pavement. It is recognized that the sensitivity and resistance of the voltmeters used before the advent of electronic, solid-state instruments were not suitable for taking consistently true readings through paving. The resistance of those voltmeters rarely exceeded 100,000 ohm per volt. In recent years, there have arrived on the market a number of electronic instruments and voltmeters, and an input impedance of 10 megohms has become quite common. These are of both the digital and analog type. An example of the digital type is the Danameter 2000 and an example of the analog is the Nilsson Model 540.

In testing, the performances of the following instruments were compared:

- Aardvark Model PEC-VM
- Miller Model H
- Nilsson Model 540

The Aardvark meter is an analog type meter which has an input resistance of 1,000,000 megohms. This is probably the ultimate which can be expected in increased input resistance. If successful results cannot be obtained at that level of resistance, it is highly unlikely that increasing the resistance would result in any improvement.

The Miller Model H has the usual 10-megohm input resistance, but in addition, it has a push button which changes the input resistance to 20 megohms. This feature, which permits the user to measure the voltage while changing the input resistance from 10 to 20 megohms, is analogous to measuring the voltage on two different scales of the same instrument. If the reading on either scale is essentially

identical, then the reading is considered correct. If there is a difference between the two readings, the correct voltage is calculated using the formula:

$$E_c = \frac{E_1 E_2 (R-1)}{RE_1 - E_2}$$

where E_c = correct voltage

E_1 = voltage reading on lower scale

E_2 = voltage reading on higher scale

$R = \dfrac{\text{Meter resistance at higher scale}}{\text{Meter resistance at lower scale}}$

When using the Miller MOdel H, the value of

$$R = \frac{20 \text{ megohms}}{10 \text{ megohms}} = 2$$

then $E_c = \dfrac{E_1 E_2}{2E_1 - E_2}$

The Nilsson Model 540 is an instrument which also has a normal input resistance of 10 megohms on voltage ranges of 0.1 volt or more. In addition, this instrument has a unique feature which the manufacturer calls "a true electronic self-balancing potentiometer". The manufacturer states that "when in the potentiometer mode the Model 540 will ignore poor contact and high resistances in the external circuit."

Thus, in the evaluation of available instrumentation, three instruments which use different approaches were considered: (1) the Aardvark PEC-VM, which has an extremely high input resistance, (2) the Miller Model H which has a convenient means of changing input resistance and calculating the true potential, and (3) the Nilsson 540 which has the electronic self balancing potentiometer.

Other instruments such as the ESD Digital and Danameter were also looked at. These other instruments have high impedance inputs (the ESD has 300 megohms), but they lack some of the special features

such as those on the Miller Model H and Nilsson Model 540. Because the Aardvark has a 1,000,000 megohm input, it can be said to be representative of the behavior of all straightforward high impedance instruments.

In addition to evaluating instruments, we also judged the various reference electrodes on the market, specifically those which are specially designed to reduce earth resistance contact such as the Tinker-Razor Model 3A, the "Fat Boy". This reference electrode is 3 inches in diameter and comes with a sponge for maintaining a moist contact to paving.

Penetrate Through Paving

In our investigation of methods for penetrating through paving, we looked for equipment which was not only able to drill holes through concrete and asphalt, but which was (1) reasonably portable, (2) relatively easy to use and (3) capable of reasonably fast performance. Harco at first worked under the assumption that it would be necessary to "seal up" the holes after they have been drilled. In order to properly seal paving with the various epoxy materials available, it is necessary to drill a "clean hole" or one in which all the fines have been removed. We learned that the State of Kansas, Department of Transportation (Reference 9) had developed techniques for drilling small diameter "clean holes" in concrete bridge decks for injecting epoxy resin for sealing. They have developed hollow stemmed, carbide drill bits to be used with vacuum equipment to remove the drilling dust and fines which could plug the holes and inhibit the effectiveness of the sealing with epoxy.

Because the Air Force indicated that it would be preferable to place permanent inserts into the drilled holes, rather than completely sealing them, the investigation into the use of "hollow stemmed" drill bits was abandoned. In addition, it was learned that there are problems in attempting to use hollow stemmed bits in asphalt based materials.

Thus, the work then focused on the use of rotary hammer drills. Our investigation concentrated on drills made specifically for drilling in concrete. Some of the other drills are made for drilling in both concrete and metal. However, experience with these drills proved them inadequate.

Penetrate Horizontally Under Paving

A number of tools are available for boring small diameter horizontal holes underground approximately 3 inches to 6 inches in diameter, for installing pipe or cable under paved areas. The best known of these tools are the Pneuma Gopher manufactured by Schramm, Inc., West Chester, Pennsylvania and Hole-Hog manufactured by Allied Steel and Tractor Products, Solon, Ohio.

Both tools are air powered and claim to be able to attain a piercing speed of up to 240 feet per hour, for distances of 100 feet or, depending upon the soil composition. Manufacturer's literature claims that it is possible to track the tool electronically using a conventional pipe locator.

In the original Harco proposal we stated that we would "explore the practicability of using these machines or adaptations of them, for placing a reference electrode with an associated lead wire at designated locations under the paving."

At a meeting on September 26, 1977 between Harco and the Air Force (Reference 10)"it was decided that further work on this method would be held in abeyance pending the outcome of the other work." Because of the reasonably "good" results obtained with the other methods described above and because this method was expected to be more unwieldy than the others, no further work was done.

Mathematical Model

In some instances, it is possible to determine the effectiveness of cathodic protection on pipes under paving on which valid measurements cannot be taken, by extrapolating from results obtained in unpaved areas. This extrapolation often uses the available information about the configuration of the piping and the geometry of the cathodic protection system together with calculated potential gradients and attenuation characteristics. Thus, the corrosion engineer, using his experience and intuition in a sense, constructs a mathematical model to make this

determination. Because of the variety of conditions and configurations encountered in underground cathodic protection work, mathematical models of this type can be substantially different from case to case.

With the advent of computer technology, we believe it to be possible to construct mathematical models which will account for all of the variables encountered. It would be the purpose of these models to calculate the potentials of structures under paved areas from readings taken in unpaved areas. In the meeting of September 26, 1977, both Harco and the Air Force agreed that research into the use of mathematical models would not be worthwhile unless the other techniques prove to be unsatisfactory. Again, because of the reasonably good results obtained with the other techniques, no work was done with this procedure.

SECTION III

DISCUSSION OF RESULTS

Instrumentation Evaluation

The testing work in which various instruments were evaluated with respect to their ability to consistently duplicate measurements taken with respect to a reference electrode in both paved and unpaved areas was performed in the paved parking lot outside the Harco Corporation building in Medina, Ohio. These tests were performed during the second half of 1977. The parking lot is paved with 4 inches of asphalt over crushed stone. A sealing coat had been applied during the summer of 1977. Immediately adjacent to the asphalt paving is a 3-foot wide concrete sidewalk, which is 3 inches thick. There is a grassed area on the other side of the concrete walk. A layout of the area is shown on Figure 2.

Initially the instruments evaluated were:

- Miller Model M-3-M
- Aardvark PEC-VM
- Miller Model H
- ESD Digital
- Dana Meter Model 2000

Two months later the Nilsson Model 540 was also included.

As expected, the Aardvark PEC-VM showed the most consistent capability for obtaining potentials through the asphalt in the parking lot comparable to those obtained in unpaved areas. A typical set of readings taken with the Aardvark is shown in Table 1. Also shown in that table are the results when attempting measurements with the potentiometer-voltmeter circuit of the Miller Model M-3-M. This latter instrument proved to be totally unsatisfactory and these results show that if valid readings are to be taken through the asphalt, the "old style" non-electronic instruments are not suitable.

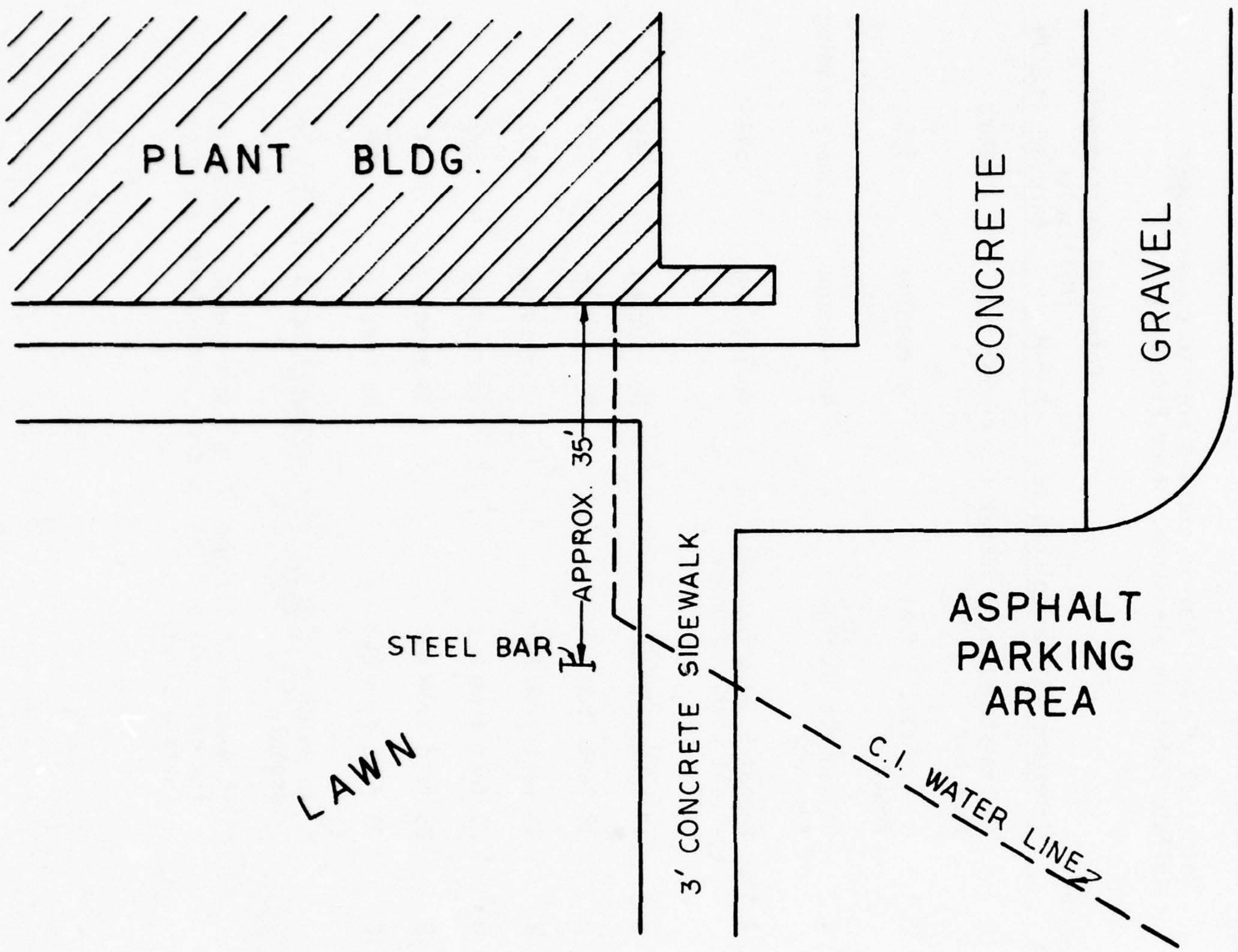

FIGURE 2 - TESTING AREA AT MEDINA, OHIO

TABLE 1. COMPARISON OF MILLER M-3-M WITH AARDVARK PEC-VM

Date: September 14, 1977

Potential of steel bar in grassed area to copper-copper sulfate reference electrode. (See Figure 2)

Reading No.	Reference Electrode Location	Potential Measurements (Millivolts) M-3-M	Aardvark PEC-VM
1	In grassed area, 6 inches from bar	-540	-540
2 *	On asphalt, 5 feet from bar	No reading	-535
3 *	On asphalt 10 feet from bar	No reading	Unstable reading
4 **	Repeat 5 feet from bar, except with pad under half cell	No reading	-540
5	10 feet from bar	No reading	-565
6	12 feet from bar	No reading	-580
7	15 feet from bar	No reading	-600
8	20 feet from bar	No reading	-590
9	25 feet from bar	No reading	-580
10	30 feet from bar	No reading	-575

* In Readings 2 & 3, half cell was placed directly on asphalt.

** In Readings 4 through 10, a paper pad was placed under the half cell and this pad was wetted with a copper sulfate solution.

Because the Aardvark has the highest input impedance of any of the instruments tested, it was used as a basis for comparison. Although it was possible to obtain readings through asphalt with the Miller Model H, those readings were almost always less negative than those taken with the Aardvark PEC-VM, as shown in a typical set of readings in Table 2. The readings in that table also show the usefulness of the 20 megohm impedance and show that the calculated potential values are within 5 percent of the values obtained with the PEC-VM. Thus, comparisons made in the work at the Harco parking lot indicate that the Miller Model H can give results which compare favorably with those obtained with the PEC-VM, although in many cases the actual reading must be calculated and cannot be read directly. The calculated results obtained at Dover AFB with the Model H were not as favorable as we shall see later in this report.

Although the Aardvark in general gave consistently good results, it exhibited some erratic behavior when a normal sized reference electrode was held in place manually on the paving. This erratic behavior was attributed to the extreme sensitivity of the instrument. The "stubby" reference electrode which can stand without being held gives more stable readings. Most of these commercial "stubby" electrodes have plugs with corrugated surfaces. Although the PEC-VM is capable of obtaining reasonably stable readings when contact to the paving is made through this corrugated plug, the use of a wetted sponge placed between the plug and the paving facilitates stability.

The PEC-VM used during the testing at Harco required AC power. It was later equipped with a battery pack for use during the testing at Dover AFB.

The work at Dover with the PEC-VM (see Appendix A for a complete description and results of the work done at Dover) showed that this instrument yielded comparable results except that on a freshly repaved and sealed asphalt surface, a reading was unobtainable with all instruments including the PEC-VM. In tests at Dover, comparing the Model H with the PEC-VM and other instruments, the calculated values

TABLE 2. COMPARISON OF MILLER MODEL H WITH AARDVARK PEC-VM

Date: September 21, 1977

Potential of steel bar in grassed area to a copper-copper sulfate reference electrode. (See Figure 2)

		Potential Measurements (Millivolts)			
			Miller Model H		
Reading No.	Reference Electrode Location	Aardvark PEC-VM	10 Megohms	20 Megohms	Calculated Value
1	In grassed area, 6 inches from bar	-525	-525	-525	-525
2	2 inches from bar, half cell all on concrete	-810	-820	-820	-820
3	6 inches from bar, half cell all directly on asphalt	-560	-305	-400	-581
4	6 inches from bar, half cell on asphalt through wet sponge	-580	-240	-335	-554
	Following measurements are potential of a water line:				
5	Half cell in grass	-535	-540	-540	-540
6	Half cell on concrete	-780	-780	-780	-780
7	Half cell on asphalt	-580	-520	-550	-584

obtained with the Model H did not compare as favorably as they did during the Medina testing work.

The ESD and Dana Meter digitals were tested at Medina. Although they were used to some extent at Dover, they were not rigorously tested there. Both of these instruments yielded surprisingly good results. As expected, the higher resistance instrument, the ESD (300 megohms) seemed to produce more consistent results than the Dana Meter (10 megohms). Both instruments exhibit a problem inherent in many digital meters, that is fluctuating changes in the numbers shown during unstable situations making it physically difficult to read the instrument.

The testing work done with the Nilsson Model 540, produced results which were comparable to those obtained with the Aardvark PEC-VM. Even though the normal input impedance of the Model 540 is 10 megohms and the readings taken at some locations on asphalt were considerably less than those taken with the PEC-VM, the use of the self-balancing potentiometer circuit yielded readings which were substantially identical to those taken with the PEC-VM. This self-balancing feature is unlike the "old style" potentiometer-voltmeter circuits in which a reading is taken on one meter movement after dial adjustments balance out the current to zero on a second movement. The Model 540 has a single push button adjustment which is held down while the needle on the movement moves upscale. A correct reading is obtained when the needle stops moving upscale. A disadvantage of the instrument is the length of time sometimes necessary to achieve complete balance. On some occassions, it was necessary to keep the button depressed for more than two minutes. With a push button control, this can be physically uncomfortable and a lever type switch rather than a push button would be an improvement. As with all potentiometer circuits, this instrument should not be used in areas of stray current. Otherwise, it appears to be a completely reliable instrument which yields readings as correct as those made with the PEC-VM. It is lighter weight and more convenient for use in the field and is less sensitive to spurious voltages.

Effect of Paving on Readings - Concrete

During the course of the testing work at Medina, an unexpected problem was noted which was entirely unrelated to the instrumentation. As can be seen from Reading No. 2 in Table 1, the potential obtained with the reference electrode placed on the concrete was different from potentials with the reference electrode placed on adjacent grassed areas and adjacent asphalt areas. In almost all cases in the Medina testing, the readings on concrete were more negative (higher in value) than those taken on the grass or asphalt a few feet away. These differences were often substantial, exceeding 150 millivolts. There was no galvanized wire mesh or reinforcing bars in the concrete to which the differences could be attributed. Neither could the differences be attributed to unusual IR drop in the paving because there was no applied cathodic protection. In one case we even dug out the soil at the edge of the concrete slab and placed a reference electrode in the soil under the slab. That reading was approximately 100 millivolts less negative than the reading taken with a reference electrode placed on the slab directly above. Because of these findings, additional experiments were initiated at the Medina facilities to see if a reason for these results could be established. A literature search was also undertaken to determine whether anyone else has reported similar findings. This work is more fully discussed in Appendix B.

Similar results were obtained in the testing work at Dover (see Appendix A) where readings on concrete were 40 to 180 millivolts more negative than on adjacent grassed or asphalted areas. At one location where the soil at the edge of 16 inch thick concrete slab was dug out, the potential to a reference electrode under the slab was -600 millivolts with the rectifier off and -940 millivolts with the rectifier on as compared to readings of -670 millivolts "off" and -1000 millivolts "on" to a reference electrode on the top of the slab directly above. It is significant that the changes in potential (delta E) with the cathodic protection current off and on were substantially the same indicating that the readings are not influenced by IR drops in the

concrete. When the reference electrode in this area is moved onto the slab 5 feet from the edge, the potentials were -740 millivolts off and -1100 on. Again the changes in potential (delta E) were not appreciably affected, but the respective readings were 140 to 160 millivolts more negative with the reference on the concrete than in the soil under concrete.

Although in most instances readings on concrete were more negative than those taken in soil, there are cases reported where the reverse condition is found. In fact, tests at Medina (See Appendix B) yielded results in both directions. The amount of moisture in the concrete had considerable effect and readings changed and drifted as water was added either physically or by rainfall.

In asking for comments from the Harco field engineers about their experience with readings on concrete, there was considerable belief that concrete influenced the readings to be lower than in soil. One comment was "most of the potentials I have personally measured appear to be low when read through concrete - although this is not necessarily always the case". This same engineer then made a statement which we consider to be highly appropriate, "I don't trust the readings".

A set of measurements taken at paved gas stations in New England suggest that in field measurements the readings on the concrete are more negative than those in soil. Table 3 lists the results of potential measurements taken on hydraulic lift cylinders at these stations. Soil readings were taken through holes drilled through the concrete and readings on concrete were taken 3 inches to 6 inches from the test holes and the surface was watered. Here again we find that all of the readings on the concrete are more negative than the readings in the soil. The differences in the "off" readings ranged from 20 millivolts to 260 millivolts.

TABLE 3. COMPARISON OF POTENTIALS IN CONCRETE AND SOIL - SERVICE STATIONS IN NEW ENGLAND

	POTENTIAL IN SOIL Millivolts		POTENTIAL IN CONCRETE Millivolts	
LOCATION	CURRENT OFF	CURRENT ON	CURRENT OFF	CURRENT ON
Roxbury, Mass.	-550	- 770	-810	-1100
Portsmouth, N.H.	-600	- 910	-800	-1060
Portsmouth, N.H.	-940	-1590	-960	-1740
Hudson, N.H.	-130	- 135	-300	- 330
Malden, Mass.	-440	- 555	-550	- 565
Stovelawn, Mass.	-475	- 490	-585	- 590
Burlington, Mass.	-670	- 860	-810	-1020
Bellingham, Mass.	-430	- 930	-600	-1070
Marborough, Mass.	-420	- 545	-565	- 575

In our search of the literature, we find as previously noted little related to the mechanics of potential measurements. The major concern in most literature is about the effect of the "contact resistance" between the reference electrode and the soil. We found only three papers (References 11, 12 and 13) in which the effects of "liquid junction potentials" is noted. Although there was nothing stated about the effect of concrete, Ewing indicates that measurements covering a range of pH 3 to pH 10 showed differences between the half cells of 4 to 6 millivolts with the half cell in the alkaline environment being positive. Scott states that "dry, porous, sandy soils may show as much as 20 millivolts variation in potential if water is added about the porous plug". In an attempt to try to learn something about the mechanism involved, we carried out tests both in the field and in the laboratory, as described in Appendix B.

The field simulation used concrete slabs 2 feet x 2 feet x 2 inches thick. As noted, there was neither consistency in the potential differences between readings in soil and on concrete, nor reproducibility. There was drifting in the readings as water was added with no definite patterns as related to amount of moisture. In most instances, the addition of water to the concrete resulted in a more negative potential although there were instances where the reverse occurred.

The laboratory simulation used a plastic container filled with soil, one half of which was paved with concrete. No significant differences in potential were measured between a half cell in the soil and one on the concrete. Nor were any significant potential differences measured between two half cells, one of which was immersed in Medina tap water of pH 6.5 and the second in a solution of pH 13.

Thus, neither the field simulation or the laboratory simulation was capable of producing the relatively large differences in potential encountered in the field work.

Effect of Paving - Asphalt

In the work done at Medina, no distorting influences were noted in readings taken with the reference electrode placed on the asphalt. Various instruments as noted were capable of reading directly "through" the asphalt. The liquid "junction effects" noted on concrete were not noted on the asphalt. In the Medina tests, although the asphalt had been "sealed", it apparently had not been sealed well enough to prevent or interfere with getting a reading. At Dover, however, there was new asphalt paving of sufficient thickness and apparently sufficiently well sealed to prevent the acquisition of a reading directly through the pavement with any of the instruments. On the other hand, in older asphalted areas which were cracked and fissured, readings were obtained easily.

It was found that readings which appeared to be real could be obtained even on the well sealed surfaces when water "bridges" connected reference electrodes placed on the well sealed surface to a crack or to an unpaved area. Thus, it is possible to obtain what is apparently a true reading on a totally insulating asphalt surface when in fact what we are actually reading is the potential at the location of a crack in the asphalt or the potential at an unpaved area which is some distance away from where the point where the reference electrode is actually placed. With all of the combinations of asphalt geometries and cracking patterns as well as the bridging effects of water on the paving, it can be appreciated that the particular potential measured at a given location may be actually totally unrelated to the true potential which exists at that location. The effect of aging on the quality of the paving, in that additional cracking could be expected as the asphalt ages, could introduce problems in reproducing true readings year after year. In summary, even though it is often possible to obtain what appears to be a reading directly "through" asphalt with the new electronic voltmeter, there are too many uncertainties as to what is actually being read to conclude that these readings are authentic.

Penetration Through Paving

Because of the indicated innate uncertainties which exist when taking potential measurements with a reference electrode placed on paving, either concrete or asphalt, even with the most sophisticated instrumentation, it is obvious that the only procedure which would make sure that the reading is that of the "true" potential is one where the reference electrode is in contact with the soil in which the structure is installed. In the large, extended paved areas at Air Force facilities, the only way to obtain contact with the soil is to drill holes through the paving. Once the hole is drilled, it is preferable to install a permanent pavement insert for future use rather than merely reseal the hole. Because the commercially available standard copper-copper sulfate reference electrodes are more than 1 inch in diameter and because it would be advantageous to keep the hole size as small as possible, we investigated ways to adapt commercial reference electrodes for use through smaller diameter inserts. Thus, we focussed our attention on doing the following tasks:

1 Acquiring the tools and know how to drill holes through both asphalt and concrete paving in thickness up to 28 inches. Hole size should be sufficiently large to accommodate commercially available pavement inserts, but as small in diameter as possible in order to expedite drilling.

2 Selecting the pavement inserts and materials for permanent installation in the drilled holes.

3 Constructing small diameter extensions (bridges) to standard copper-copper sulfate half cells which can be inserted through the drilled holes to make adequate contact to the underlying soil.

Initially we believed it necessary to have a "clean" hole free of drilling dust and fines. We learned that state and federal highway agencies have had a need for drilling these same types of holes for the repair technique involving the injection of epoxy into bridge deck delaminations (hollow planes). As part of this study, we interviewed F. W. Stratten of the State Highway Commission of Kansas who had developed hollow-stemmed, carbide tipped drills, adapted for use with vacuum cleaner type equipment which would evacuate the drill dust through the hollow stem of the drill.

Although we have reason to believe that the equipment developed for this purpose is capable of performing as claimed, it was decided that it was not capable of drilling holes sufficiently large in diameter and depth for our purposes. The equipment necessary for this drilling is specialized and expensive. It is our opinion that the stringent "clean" hole requirement necessary for effective epoxy injection is not required for our application. We believe that holes drilled with commercially available equipment would be adequate.

In selecting equipment required for hole drilling, we evaluated the equipment on the basis of the following considerations:

1 Availability
2 Capability in both asphalt and concrete
3 Portability
4 Facility of use
5 Speed of penetration
6 Cost

As a result of this evaluation, we selected the rotary hammer drill as manufactured by Hilti Fastening Systems, Stanford, Connecticut, Model TE 60. This drill and the accessory drill bits are judged to be fully adequate for the task on the basis of the above considerations. The only possible reservation might be cost. At the time this work was done, October 1977 to May 1978, the cost of the TE 60 was $695.00. This price does not include the tungsten carbide tipped drill bits. It was found that two drill bits are required to achieve the type of hole we considered appropriate and

convenient. We used a 1-3/4 inch drill to drill a hole adequate for installing a plastic pavement insert and then used a 7/8 inch drill for the remainder of the penetration through the paving. A 1-3/4 inch drill bit with an effective drilling length of 11-5/8 inches costs $152.00 and a 7/8 inch drill bit with an effective drilling length of 32 inches costs $196.00. Hilti also manufactures the Model TE 17, which costs $405.00. This model is capable of drilling holes only up to 7/8 inch diameter.

The TE 60 can be energized from a 115 VAC outlet and according to the manufacturer's specifications will take 7.7 amperes. In order to achieve complete portability, we used a gasoline fueled motor generator for power. We selected a 1200 watt, motor generator, Model RAIZO as manufactured by the McColloch Corporation, Los Angeles, California. This generator is driven by a two cycle engine and is designed with a rotating field rather than a rotating armature, thereby eliminating the need for brushes. It is our opinion that although this feature makes this machine somewhat superior to other similar generators, most other motor generators rated to deliver at least 1200 watts at 115/VAC should be equally as effective in providing power to the TE 60. A generator adequate for this purpose should be available for less than $300.00.

In the testing work at Dover, this equipment proved to be completely satisfactory. (See Appendix A) Holes were drilled in both asphalt and concrete; the asphalt was approximately 8-1/2 inches thick and the concrete was approximately 16 inches thick. The 1-3/4 inch bit was used for the top 6 inches for placing the pavement insert, and the remainder of the hole used the 3/4 inch bit. The elapsed time for the drilling was less than 5 minutes in every case. It is assumed that the asphalt and concrete through which this drilling was accomplished at Dover is representative of typical pavements used at most Air Bases and that this type of drilling equipment will be adequate for almost any type of paving likely to be encountered up to a thickness of 32 inches.

Pavement Inserts

For pavement inserts, we selected the 1-3/4 inch x 6 inch plastic inserts manufactured by Central Plastics Company, Shawnee, Oklahoma. This insert has a cadmium plated, socket head, pipe plug to provide a 3/4 inch opening which can be removed easily for insertion of the reference electrode. In the work at Dover, these inserts were easily installed and sealed in the drilled holes. There was no difficulty in sealing the inserts using Future Patch. The 3/4 inch opening when the pipe plug was removed was adequate for the insertion of the modified copper-copper sulfate reference electrode. The plastic Auto-Test Insert manufactured by Heath Survey Consultants may also be used. This has a 1-5/8 inch diameter x 5 inch long plastic body with a removable metal plug at the top which provides a 3/4 inch opening. A 1-5/8 inch drill bit is required for installing the Heath pavement insert. Both inserts can be driven in place with a rubber hammer or block of wood.

Reference Electrodes

As part of this study, Harco built a number of prototypes of copper-copper sulfate half cells with "salt bridge" extensions. There were two types of extensions, one constructed of clear flexible 3/8 inch polyethylene tubing and the other of clear rigid 5/8 inch tubing. At the Dover tests, both performed adequately although there was some question as to the suitability of the wooden end plug. If half cells such as these are manufactured for general use, a ceramic type plug should be used. Because pressure was needed for contact of the half cell in the aggregate below the paving, the rigid extension was better suited for this work. In the initial stages of this study, the use of a small diameter reference electrode was contemplated, but the salt bridge extension was considered to be more practical.

It is our opinion, that the testing of a cathodic protection system on piping which is under paved areas at Air Force Bases can be readily accomplished through the drilled holes using pavement inserts and specially adapted reference electrodes. A "Guide for Drilling Holes and Installing Inserts" is given in Appendix C.

It is possible to have a relatively high contact resistance even through the holes in the pavement, unless all debris and drilling fines are removed from the hole. Furthermore, sufficient water should be poured into the hole to saturate the bottom surface before attempting to take any potential measurements. The effects of high contact resistance can also be minimized by using an electronic instrument such as those evaluated during this study.

United States Air Force Testing

Subsequent to our testing, the civil engineering personnel at Dover AFB installed several Heath pavement inserts using the pneumatic drill and a 1-5/8 inch drill bit authorized by Table of Allowance 008, National Stock Number 3820-00-275-2615. The time required for equipment set-up, drilling and installing the insert complete was less than 8 minutes. In addition, the drilling fines were easily removed by blowing compressed air through the drill bit into the bottom of the hole. The procedure used by the Dover AFB personnel is also included in Appendix C.

SECTION IV

CONCLUSIONS

1 Older type non-electronic instruments even those with potentiometer voltmeter circuits were deficient in performance where contact resistance was extremely high such as on asphalt paving.

2 All of the electronic voltmeters tested were effective in reading potentials through almost any pavement except for newly laid, well sealed asphalt. An evaluation of each of the instruments tested giving the advantages and limitation of each, is given in Appendix D.

3 Even where readings were obtained on paving, it was found that errors resulting from the effect of the pavement itself, both asphalt and concrete, make apparently correct readings questionable.

4 On asphalt, there is uncertainty as to whether the potential read is indeed the actual potential at the specific reference electrode location. For example, though readings were not obtainable on newly laid, well sealed asphalt even with the highest resistance voltmeters, "water bridges" to cracked asphalt or unpaved areas produced an apparent authentic reading at that well sealed location; that reading could be totally unrelated to the actual reading at that location.

5 On concrete, it was found that readings differed from adjacent readings in soil often by substantial amounts (in excess of 100 millivolts). There was no consistency found when trying to correlate these differences. Most often readings on concrete were of higher negative value than readings in soil, but reverse conditions were also found. Rarely were the readings on concrete and adjacent soil identical.

6 Laboratory simulations comparing measurements on concrete with those in soil did not duplicate the findings in the field.

7 Measurements of potentials between reference electrodes in waters of different pH did not yield values which would account for the effect of the concrete on potentials measured in the field.

8 Penetrations, sealed with pavement inserts, were easily made through both asphalt and concrete pavements of the thicknesses encountered at Air Force facilities.

9 Copper-copper sulfate half cells modified to permit placement through pavement inserts perform effectively.

SECTION V
RECOMMENDATIONS

1 Where contact resistance between the reference electrode and a surface is high, use an electronic voltmeter with an input resistance of at least 10 megohms. The higher the resistance, the better. Do not use older style analog meters even those with potentiometer-voltmeter circuits.

2 Avoid taking readings on either asphalt or concrete paving. If such readings are considered to be essential and penetrations through the pavement cannot be made, be aware of the errors that are introduced by both the asphalt and concrete.

3 Where truly accurate potential readings are required, penetrate the pavement by drilling and installing plastic inserts as described in Appendix C.

4 In taking readings through the pavement penetrations, minimize the effect of high resistance contacts in the aggregate under the paving by saturating the bottom surface of the hole with water.

REFERENCES

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APPENDIX A

TEST RESULTS - DOVER AFB

APPENDIX A

TEST RESULTS - DOVER AFB

INTRODUCTION

Demonstration validation tests as required under this contract were conducted on April 11 and 12, 1978 at two sites provided by the Air Force at the Dover Air Force Base, Dover, Delaware. The first site was along Ramp Road east of 8th Street, north of Building 582 and the second site was west of the POL pit, north of Building 501, the Operations Control Center. Layouts of these sites are shown on Figures A-1 and A-2.

Those participating in this testing were:

Bernard Husock	Harco Corporation
John Hennessy	Harco Corporation
James Dimond	Harco Corporation
Paul Rothman	Harco Corporation
Major Roger Girard	U.S. Air Force/CEEDO
Miles Pelton	U.S. Air Force/Dover AFB

At the first site, measurements were taken along the 10 inch Fuel Line. As Figure A-1 shows, that line runs beneath a variety of surface conditions in this area, namely: (1) newly laid and sealed asphalt, (2) grassed area and (3) a concrete ramp. The roadway immediately north of the line has cracked and fissured asphalt as well as concrete paving. There is a test box in which there is a test wire connected to the pipe and there is a rectifier which energizes a deep anode bed along 8th Street just north of the pipeline.

At the second site, readings were taken on a POL line which runs under a grassed area as well as under an asphalt covered concrete slab. Contact to the line was made inside the POL pit.

OBJECTIVES

The major objectives of the testing work performed were as follows:

1 To determine whether effective test holes can be expeditiously drilled through the types of paving encountered at Air Force facilities with the tools and procedures developed by Harco.

2 To determine how well (or poorly) the various "state-of-the-art" instruments perform on Air Force paving.

3 To determine whether valid readings can be made using the reference electrode adapted for the purpose of reading through drilled holes.

INSTRUMENTS EVALUATED

The primary emphasis was placed on evaluating the following instruments:

1 PEC-VM, Modular High Impedance Voltmeter
Aardvark Instruments

2 Model H, Multi-Combination Meter
Miller Company

3 Model 540 Volt-Ammeter
Nilsson Electrical Laboratory, Inc.
New York, New York

Also used to a small degree during the testing work was the Danameter Model 2000.

DRILLING EQUIPMENT

The following equipment was used for drilling the required holes in the pavement:

1 TE 60 Rotary Hammer Drill
115 volts AC 50/60 Hertz, 7.1 amperes
Hilti Fastening Systems
Stamford, Connecticut

2 Drill Bit
Hilti TE 60/WB - 7/8 x 36
Catalog No. 56200036
7/8 inch diameter - 36 inches long
Effective drilling length - 32 inches

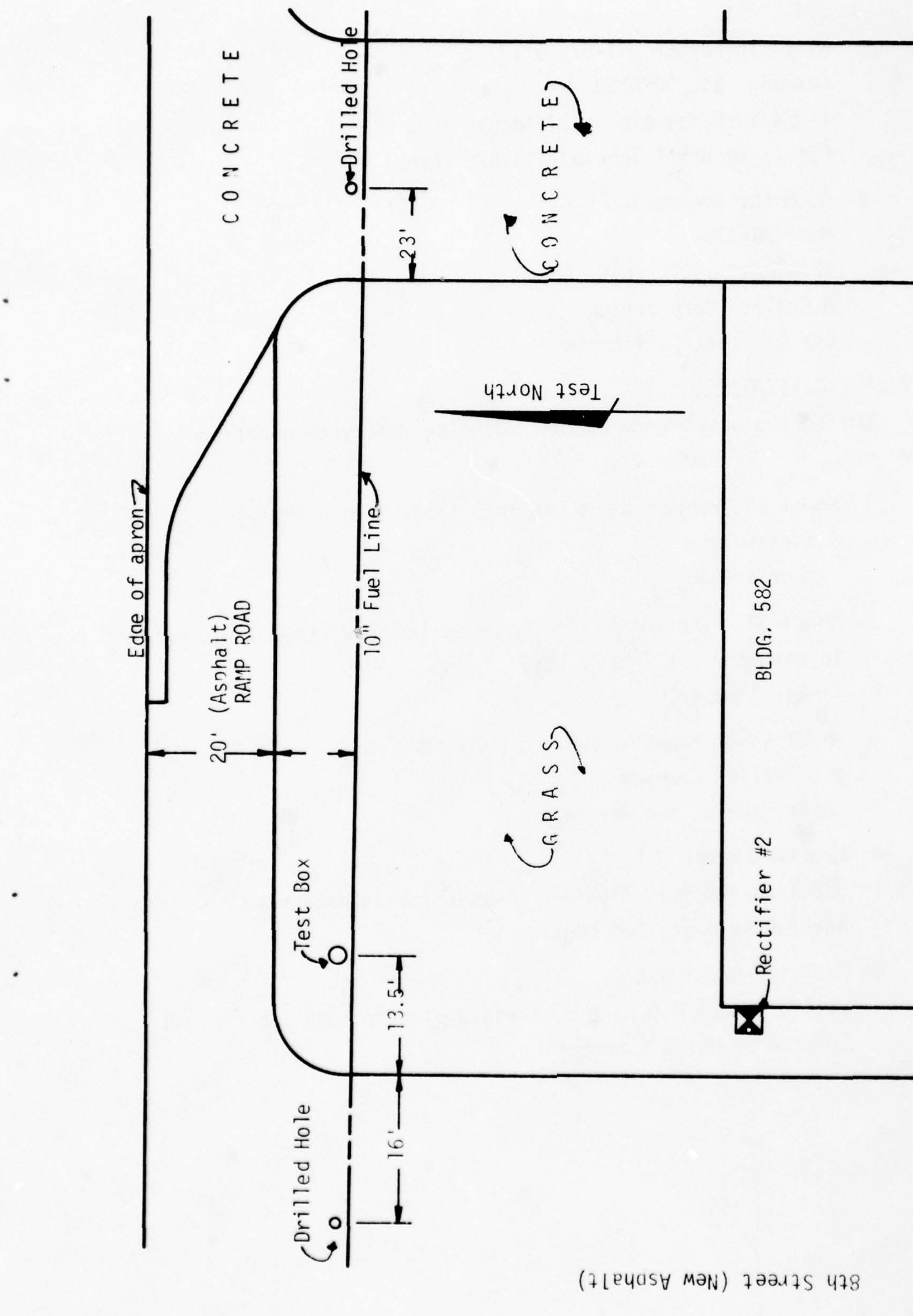


FIGURE A-1 TEST SITE #1

3 Drill Bit
Hilti TE 60/DEF - 1-3/4 x 17
Catalog No. 5620160
1-3/4 inch diameter - 17 inches long
Effective drill length - 11-5/8 inches

4 AC Motor Generator
Model RAIZO
1200 watts, 115 volt, AC
McCulloch Corporation
Los Angeles, California

REFERENCE ELECTRODES

During the testing work, the following reference electrodes were used:

1 Model 6A, copper-copper sulfate 1-1/4 inch diameter x 6 inches long
Tinker & Rasor

2 Model 3A, "The Fat Boy" - copper-copper sulfate, 3 inches in diameter x 5 inches long
Tinker & Rasor

3 Model RE-3, copper-copper sulfate
M.C. Miller Company
Upper Saddle, New Jersey

4 Modified Model 6 A
3/8 inch x 2 feet flexible plastic tubing extension
Adapted by Harco Corporation

5 Modified Model 6 A
With 5/8 inch O.D. x 2 feet rigid plastic tubing extension
Adapted by Harco Corporation

INSERTS

The pavement inserts placed in the drilled holes were:

Plastic Pavement Inserts
1-3/4 inch diameter x 6 feet long
Central Plastics Company
Shawnee, Oklahoma

These were sealed into place using:

Future Patch
Asphalt Cold Patch
21st Century Paving & Construction Materials, Corporation
Solon, Ohio

RESULTS AND DISCUSSION

Test Holes

Two holes were drilled at the first test site. One hole was through the asphalt on 8th Street directly above the 10 inch fuel line and the other was through the concrete ramp leading to Building 582, also directly above the 10 inch fuel line. See Figure A-1. In both cases, the 1-3/4 inch drill bit was used to drill a hole 6 inches deep, deep enough to accommodate the pavement insert, and then the 7/8 inch drill was used to penetrate the remainder of the paving. All the machines performed satisfactorily and the holes in both asphalt and concrete were drilled in less than 5 minutes elapsed time. No water was necessary for the drilling.

The hole through the paving at the second test site was also drilled without difficulty. The paving at that site was asphalt over concrete.

Pavement inserts were easily installed and the Future Patch material appears to provide an adequate seal.

Potential Measurements

Site No. 1

We first established the normal pipe-to-soil potential which exist on the ten inch fuel line by taking a potential profile along that line in the grassed area. Readings were taken with the reference electrode placed directly above the line as well as 20 feet south of the line. The profile was taken first with the rectifier unit de-energized and then repeated with the rectifier cycled on and off.

The values of potential measured are listed in Table A-1.

These potential measurements show that there are no unusual potentials along this line which would interfere with the tests in paved areas. There are no fluctuating stray currents; the potential gradients and changes in potential resulting from the energizing of the cathodic protection system are those which would be expected on a coated pipeline close to the ground bed.

At the location where the hole was drilled in the asphalt on 8th Street, it was not possible to obtain a potential with any of the instruments even after "roughening and watering" the surface. Using the modified half cell with the rigid extension through the drilled hole, the following readings were obtained with the rectifier off:

Nilsson	-720
Aardvark	-720 to -750 millivolts

The reading with the Nilsson appeared to be more stable and it might be more accurate than the reading on the Aardvark. Adding water to the hole did not change the reading. Thus, the modified reference electrode appeared to function effectively. The reading of -720 millivolts is more negative than the reading in the grassed area 10 feet to the east. The rectifier was "off". The "on" reading in the hole of -1000 millivolts is approximately the same as those obtained in the grassed area.

More extensive testing was performed at the hole drilled in the concrete ramp. A summation of the results obtained from the testing at the location is given in Table A-2. These tests indicate the following:

1 Despite the hole drilled through the concrete, there was apparently enough aggregate and fines to produce high resistance contacts sufficiently large to necessitate the use of a high impedance instrument.

2 The readings obtained with the Nilsson 540 and the Aardvark were close enough to one another in most of the tests to indicate that the readings were valid.

3 The calculated values obtained with the Model H were in most cases sufficiently different from the values read on the other instruments to indicate that the Model H calculated values are in error.

4 The readings taken with the various types of modified reference electrodes indicate that these extensions can be used for this application. The results in Test No. 12 using the 3 foot extension, showed potentials less negative than generally obtained and could be attributed to some cell contamination.

5 The readings on the surface of the concrete were more negative than those in the hole.

6 The changes in potential (Δ E) obtained when turning the rectifier on and off were substantially the same on the surface and in the hole.

In order to confirm whether the concrete itself could influence the potential, a series of readings were taken along the west edge of the ramp to Building 582. A summation of the results obtained are listed in Table A-3. These readings were taken with conditions as found; no water was poured on the concrete during the taking of this set of readings. It can be seen that all the readings were substantially more negative with the reference electrode on the concrete than they were on the adjacent unpaved area.

TABLE A-1. POTENTIAL PROFILES - 10 INCH FUEL LINE
TEST SITE NORTH OF BUILDING 582 IN UNPAVED AREA

Reading No.	Location of Reference Electrode	Static Potentials (Millivolts) Over Line	Static Potentials (Millivolts) 20 Feet South	Cycled Potentials (Millivolts) Over Line Current Off	Cycled Potentials Over Line Current On	Cycled Potentials 20 Feet South Current Off	Cycled Potentials 20 Feet South Current On
1	Edge of asphalt at 8th Street	-640	-620	-680	-1050	-640	-1400
2	2.5 feet east	-640	-600	-660	-1050	-640	-1350
3	5 feet east	-620	-600	-610	- 990	-650	-1300
4	7.5 feet east	-640	-600	-620	-1000	-640	-1250
5	10 feet east	-620	-590	-670	-1050	-630	-1200
6	12.5 feet east	-620	-600	-690	-1050	-670	-1200
7	15 feet east	-620	-600	-680	-1050	-650	-1150
8	17.5 east	-620	-560	-670	-1050	-560	-1050
9	20 feet east	-620	-560	-700	-1050	-600	-1050
10	73 feet east	-580	--	-580	- 930	-550	- 800

All readings taken with Nilsson Model 540 voltmeter. Readings with other instruments at some locations were essentially the same.

TABLE A-2. POTENTIAL MEASUREMENTS AT HOLE IN CONCRETE RAMP NORTH OF BUILDING 582

Test No.	Half Cell Location and Conditions	Millivolts Potential - 10 Inch Fuel Line Instrument Used Nilsson 540	Miller Model H	Aardvark
1	On concrete - dry	-740	-720	-740
2	On concrete - after wetting	-760	-750	-750
3	In hole - dry	-580	-468*	-540
4	In hole - after 15 minutes**	-520	-590*	-500
5	In hole - after firmly seating half cell	-640	-590*	-600
6	In hole - after installing insert	-640	-1055*	-620
7	On concrete surface - rectifier "on"	-1100	-1100	-1050
8	On concrete surface - rectifier "off"	-760	-740	-740
	On concrete surface	340	360	310
9	In hole - half cell with 2 ft. rigid extension, rectifier "on"	-960	-750	-910
10	In hole - half cell with 2 ft. rigid extension, rectifier "off"	-620	-470	-580
	E - half cell in hole	340	280	330
11	Flexible extension in hole	-610	-600	-600
12	3 ft. rigid extension in hole	-510	-530	-510

*These are calculated values using reading taken on the 10 megohm and 20 megohms scales.

Those readings were:

	10 megohms	20 megohms
Test No. 3	-320	-380
Test No. 4	-390	-470
Test No. 5	-400	-580

**A reading taken with the Danameter during this test was -325 millivolts.

TABLE A-3 POTENTIAL MEASUREMENTS ALONG EDGE OF CONCRETE RAMP SLAB IN AS FOUND CONDITION

		Reference Electrode (millivolts)		
No.	Location	On Concrete at Edge of Slab	On Concrete 5 feet east of Edge	On Grass at Edge of Slab
1	Over 10 Inch Fuel Line	-710	-780	-550
2	5 feet south of No. 1	-780	-740	-560
3	5 Feet south of No. 2	-740	-740	-550
4	5 feet south of No. 3	-730	-740	-550
5	5 feet south of No. 4	-740	-750	-550
6	5 feet south of No. 5	-720	-740	-540
7	5 feet south of No. 6	-760	-750	-540
8	5 feet south of No. 7	-750	-750	-520

In an attempt to determine whether readings are influenced by water, the set of readings were repeated, this time with water "bridging" between the reference electrode on the concrete over to the unpaved area. The results obtained are listed in Table A-4. The addition of water did not have any appreciable effect; most of the readings were slightly more negative, some were unchanged and one reading was less negative. Again, the readings on the concrete were all more negative than those taken in the adjacent unpaved area.

TABLE A-4 POTENTIAL MEASUREMENTS ALONG EDGE OF CONCRETE RAMP - WATER ADDED - BRIDGED TO GRASS

		Reference Electrode (millivolts)		
No.	Location	On Concrete at Edge of Slab	On Concrete 5 feet east of Edge	On Grass at Edge of Slab
1	Over 10 inch Fuel Line	-690	-800*	-580
2	5 feet south of No. 1	-790	-760	-560
3	5 feet south of No. 2	-760	-740	-560
4	5 feet south of No. 3	-740	-740	-560
5	5 feet south of No. 4	-780	-740	-540
6	5 feet south of No. 5	-770	-740	-550
7	5 feet south of No. 6	-780	-780	-540
8	5 feet south of No. 7	-790		

*For this reading water was added but not "bridged" to unpaved area.

With the concrete in its wet condition, readings were taken along the edge of the slab with the rectifier unit cycled "on" and "off". These results are listed in Table A-5. The readings with the half cell placed on the concrete were all more negative than readings obtained with the half cell placed in the soil right next to the concrete. The two half cell locations were almost contiguous and the difference in potential cannot be attributed to the way the half cell views the pipe. Despite these differences which at most of the locations were as much as 200 millivolts, the changes in potential (delta E) with the rectifier cycled off and on were essentially the same as can be seen from the values listed in Table A-6. Therefore, the differences between the readings taken with the half cell on the concrete and those taken in the soil cannot be attributed to IR drop in the concrete.

TABLE A-5. Potential Measurements Along Edge of Concrete Ramp Rectifier Unit Cycled "OFF" and "ON"

		Millivolts					
		Potential On Concrete at Edge		Potential On Concrete 5 Feet from Edge		Potential On Grass at Edge	
No.	Location	Off	On	Off	On	Off	On
1	Over 10 inch Fuel Line	-700	-1025	-800	-1100	-580	-920
2	5 feet south of No. 1	-800	-1100	-750	-1100	-550	-900
3	5 feet south of No. 2	-750	-1100	-750	-1050	-550	-900
4	5 feet south of No. 3	-750	-1050	-750	-1050	-550	-900
5	5 feet south of No. 4	-700	-1050	-750	-1050	-550	-850
6	5 feet south of No. 5	-750	-1050	-750	-1050	-550	-850
7	5 feet south of No. 6	-750	-1050	-	-	-500	-800

TABLE A-6. CHANGES IN POTENTIAL ALONG EDGE OF CONCRETE SLAB RECTIFIER UNIT CYCLED "OFF" AND "ON"

No.	Location	Changes in Potential (Δ E) millivolts On Concrete At Edge	On Concrete 5 feet from Edge	On Grass at Edge of Concrete
1	Over 10 Inch Fuel Line	325	300	340
2	5 feet south of No. 1	300	350	350
3	5 feet south of No. 2	350	300	350
4	5 feet south of No. 3	300	300	350
5	5 feet south of No. 4	350	300	300
6	5 feet south of No. 5	300	300	300
7	5 feet south of No. 6	300		300

As a final confirmation in determining the effect of the concrete on the potential reading, the edge of the concrete slab was excavated at Location No.1 and a reference electrode was placed in the soil under the slab and that reading was compared to the reading obtained with the same reference electrode placed on the slab directly over that location. With the rectifier unit off and on, the readings in the soil were -600 and -940 millivolts and the readings on the concrete were -670 and -1000 millivolts. On the surface in the soil right next to the concrete, the readings were -600 and -950 millivolts.

Although the difference at this location between the reading on concrete and soil were not as large as the differences at some other locations, the potential on concrete were 50 to 70 millivolts more negative than the potentials in soil.

A number of "exploratory" type readings were taken along Ramp Road, north of the fuel line. This area was paved with older asphalt which was cracked and fissured in many places and the concrete pad extended into this area. The readings are difficult to tabulate in a logical form, but we found that on the older asphalt it was possible to obtain apparently authentic potential measurements and the readings on the

three instruments were within 10 percent of one another. Readings on concrete were as much as 200 millivolts more negative than readings on the older asphalt right next to it but the delta E values with the rectifier cycled were essentially the same.

It was during this "exploratory" work that we saw the bridging effect that water produced on asphalt. Although readings were unobtainable on well surfaced asphalt, the running of a water path over to nearby cracked asphalt or to nearly soil, resulted in an apparent reading at the well surfaced asphalt.

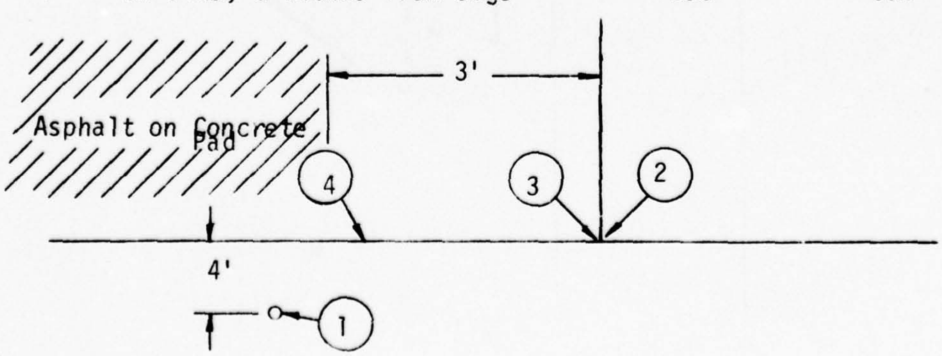
Site No. 2

The results obtained at this site were similar to those obtained at Site No. 1.

Table A-7 lists readings taken on the asphalt roadway and on the asphalt covered concrete pad extending from this roadway. Although apparently authentic readings were obtained with both the Aardvark and the Nilsson 540, the Aardvark exhibited some instability while the Nilsson was somewhat more reliable. Before the "final" reading was obtained with the Nilsson, it was necessary on some occassions to depress the potentiometer button for a time period of two or three minutes while the reading climbed.

TABLE A-7. POTENTIAL MEASUREMENTS AT SITE NO. 2

NO.	Location	Potential (millivolts) Aardvark	Nilsson 540
1	On asphalt	-540	-620
2	In dirt in hole at edge of slab	-560	-560
3	On pad at edge of slab	-600	-580
4	On slab, 3 inches from edge	-590	-590



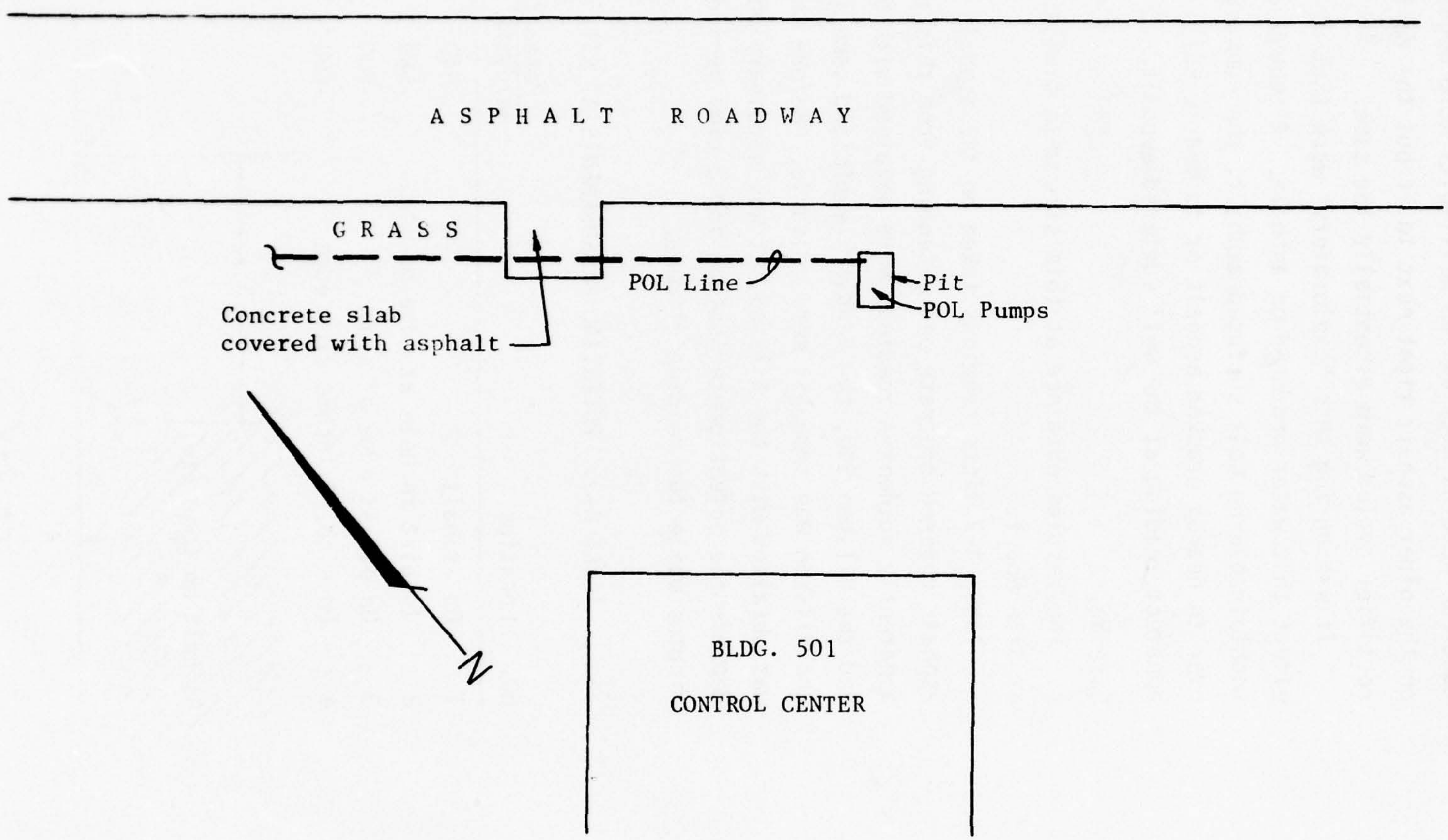


FIGURE A-2 TEST SITE #2

Measurements taken through the drilled hole at the asphalt covered concrete pad are listed in Table A-8. Again we see that the concrete seems to be responsible for making the reading more negative. It is interesting to see that the reading taken on the asphalt which covers the concrete shows a less negative reading than the one taken on the concrete after the asphalt was removed. The reading at the bottom of the drilled hole in the soil was less negative than the reading taken with the half cell on the concrete. It is noteworthy that the potential became more negative when the hole was filled with copper sulfate solution. This increase was attributed to the "bridging" effect between the soil and the concrete.

TABLE A-8. POTENTIAL MEASUREMENTS AT DRILLED HOLE ASPHALT COVERED CONCRETE PAD - SITE NO. 2

No.	Reference Electrode Location	Millivolts Nilsson 540	Millivolts Model H
1	Top of asphalt	-530	-
2	Drilled through 2" asphalt, cover to top of concrete - dry	-690	-680
3	Same as No. 2 - wet	-640	-630
4	In hole drilled through pad, no water	-580	-580
5	Same as No. 4 - added CuSo4 solution to fill hole	-640	-620
6	Drilled 2" into dirt under pad	-600	-590

The measurements taken at and through this hole illustrate the difficulties which are present when taking readings in paved areas. Thus, at the identical location above the POL Line, readings ranged from -530 millivolts to -690 millivolts. This serves to show the need to question every measurement. Just because a reading is obtained, we cannot assume that it is indeed the true potential.

APPENDIX B

EFFECT OF CONCRETE CONTACT ON POTENTIAL MEASUREMENTS

APPENDIX B

EFFECT OF CONCRETE CONTACT ON POTENTIAL MEASUREMENTS

One of the most significant results of this study was the finding that the contact between the reference electrode and a concrete surface, in and by itself affects the potential measured. This was an unanticipated result and it is somewhat surprising that it has apparently not been noticed previously by cathodic protection workers. It appears that thinking to date assumed that as long as an instrument is capable of obtaining a reading through concrete, that reading was correct. Although the Harco proposal did not foresee the investigation of this particular phenomenon, we thought it worthwhile to spend some time in trying to determine what might be the reason for the differences in potential which were noticed between a reference electrode placed on a concrete surface and one placed in the soil right next to the concrete or directly under the concrete. As noted in this report, these differences were observed during the testing at the Harco Medina Plant and were confirmed at Dover AFB.

An exploratory investigation was undertaken as follows:

1 Literature search
2 Field simulation
3 Laboratory tests

LITERATURE SEARCH

The literature search found that although there has been some concern with how to obtain a reading on concrete, there seemed to be confidence that once a reading was obtained it would be the actual reading at that location. At least, we could find no indication of anyone questioning the correctness of the readings.

Much of the basic laboratory work in developing the copper-copper sulfate half cell as a reference electrode was performed by Dr. Scott Ewing. This work is reported in a very complete and definitive paper entitled "The Copper-Copper Sulfate Half-Cell for Measuring Potentials in the Earth", published in the 1939 American Gas Association Proceedings.

Although Ewing did not mention the effect of placing the half cell on pavement, concrete or otherwise, the one item of particular concern is what he refers to as "liquid junction potentials in and near the porous pot in soils". His concern is related to the mechanism in which a potential difference is found between two solutions of the same salt of different concentrations. Because "some soils are acid and others are alkaline, one porous pot placed in contact with an acid soil and another in contact with an alkaline might be expected to give rise to uncertain potentials because of differences in the liquid junction potentials in the porous pots and between the soils".

He then discusses testing work in which he compares potentials taken in four soils, two of which are strongly acid, one is alkaline and one is neutral. He found a difference of 4 millivolts between the potentials in the acid and most alkaline soils, the electrode in the alkaline soil being positive.

Dr. Gordon Scott in his work described in "The Copper Sulfate Electrode", published in Corrosion Magazine, March 1958, states that "one source of error in copper sulfate electrode readings is the potential at the junction between the plug and the soil". He indicates that these potentials are a result of "concentrations and other differences" and states that dry, porous, sandy soils can show as much as 20 millivolts variation when water is added.

Kenneth G. Compton in his paper, "Location of the Half Cell in Measuring Potentials of Structures to Earth", published in Corrosion, September, 1961, describes work done by Pope in which "variations in potential between the half cells of as much as 26 millivolts depending upon where the cells were placed and upon whether the earth was freshly dampened with tap or salt water". Compton then indicates that there is a possible error of approximately 40 millivolts and that "these errors are due to variability of the liquid junction potentials encountered in measurements through an electrolyte as complex as damp earth".

FIELD SIMULATION TESTS

Tests to determine the effect of concrete were performed outside the Harco Medina Plant. Concrete slabs, each of which measured 2 feet x 2 feet x 2 inches thick and which had no metallic reinforcing, were each placed on previously prepared soil. A series of potential readings with respect to a driven steel bar were taken with the reference electrode in contact with the concrete as well as in contact with the soil adjacent to each slab.

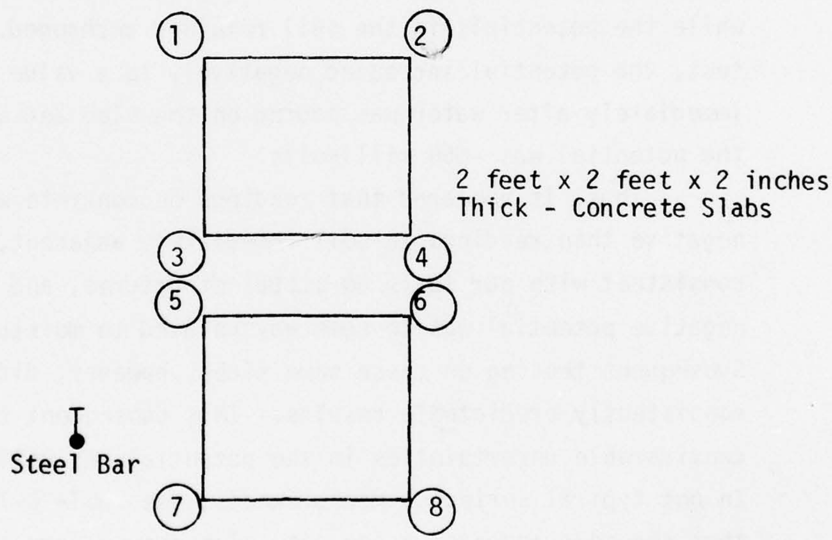
The very first series of potentials taken indicated little difference between readings on concrete and readings in soil; all readings were in the range of -485 to -535 millivolts at various locations around the edge of the slabs. But when water was poured on the slabs, the potentials on the concrete became more negative while the potentials in the soil remained unchanged. During one such test, the potential increased negatively to a value of -790 millivolts immediately after water was poured on the slab and after 15 minutes the potential was -850 millivolts.

Thus, it appeared that readings on concrete would all be more negative than readings in soil immediately adjacent, a finding consistent with our tests on actual structures, and that the increased negative potential was in some way related to moisture content. Subsequent testing on these same slabs, however, did not result in consistently predictable results. This subsequent testing found considerable uncertainties in the potentials as well as contradictions. In one typical series of measurements, see Table B-1, it was found that the measurements on the same slab showed some readings on the concrete to be more negative than corresponding readings in the soil, while other readings on concrete were less negative.

In most cases, we found that adding water to the slab changed the readings in some cases more negative and some cases less. (See Table B-1) When the slab dried, the readings returned to the value before water was added. However, there were times when the addition of water had no perceptible effect perhaps because the slabs were already moisture saturated.

TABLE B-1. POTENTIAL MEASUREMENTS ON CONCRETE SLABS

No.	Steel Bar Potential (Millivolts) No Water Added to Slabs In Soil	On Concrete	Water Added In Soil	On Concrete
1	-690	-680	-660	-720
2	-670	-730	-640	-780
3	-680	-710	-660	-680
4	-680	-710	-660	-760
5	-720	-700	-640	-660
6	-710	-740	-690	-700
7	-740	-700	-700	-680
8	-740	-640	-700	-660



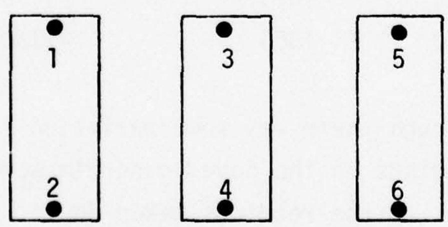
At the Medina Plant, there are a group of steel tanks which are situated under concrete and which are cathodically protected. Potential measurements have been taken on these tanks a number of times with the reference electrode placed at various places on the concrete and compared to readings taken through the drilled holes at those same locations. A typical set of readings is shown in Table B-2.

Of the six locations at which readings were taken, with the rectifier off, the readings on concrete were more negative than the readings in the hole at four locations, the reading in the hole was more negative at one location and at one location the readings were approximately equal.

In addition, the changes in potential (delta E) when the rectifier was cycled, were different on the concrete from those in the soil. The difference might be a result of the influence of the metal in the concrete. But here again there was no consistency in the result; at three locations the delta on the concrete was greater while at the other three locations the delta in the soil was greater.

TABLE B-2. POTENTIAL MEASUREMENTS ON 3 - 6000 GALLON TANKS UNDER 6 INCH THICK CONCRETE WITH STEEL MESH
METER - MILLER MODEL H

	Potential Measurement (millivolts)					
	Rectifier Off		Rectifier On		Change (Δ E)	
Location No.	On Concrete	In Hole	On Concrete	In Hole	On Concrete	In Hole
1	-832	-835	-942	-965	110	130
2	-927	-800	-1125	-980	198	180
3	-745	-725	-809	-825	64	100
4	-864	-775	-1090	-963	226	188
5	-926	-1010	-1070	-1110	144	100
6	-980	-890	-1260	-1300	280	410



LABORATORY SIMULATION

Two experiments were performed to try to determine the parameters which might be responsible for the apparent influence concrete exerts on the potential readings.

In the first experiment, a plastic container 12 inches long x 5 inches wide x 6 inches deep was filled to a depth of four inches with soil. One half of the surface was paved with concrete and the other half was left exposed. A galvanized steel rod was inserted into the soil and the potential of that rod was measured with respect to a reference electrode placed in the soil and then to one placed on the concrete. A number of 2 inch thick concrete slugs were cast and additional readings were taken using these slugs on top of the concrete to simulate increased paving thickness. Readings were taken periodically from March 8 to March 22, 1978. These readings are listed in Table B-3.

TABLE B-3. POTENTIAL MEASUREMENTS IN PLASTIC CONTAINER

Date	Half Cell in Soil	Half Cell On Concrete	One 2 Inch Thick Slug Added	Two 2 Inch Thick Slug Added
3/8/78	-1100	-1100	-	-
3/9/78	-1100	-1100	-	-
3/10/78	-1100	-1100	-	-
3/13/78	-1060	-1100	-1150	-1300
3/14/78	-1050	-1060	- 960	- 950
3/15/78	-1050	-1050	-1000	- 900
3/16/78	-1050	-1050	-1000	- 900
3/20/78	-1070	-1070	-1150	-1100
3/21/78	-1060	-1070	-1150	-1050
3/22/78	-1050	-1060	-1150	-1040

Although there was some variation in potential from day to day, the readings on the paved concrete were for the most part almost identical to the readings taken in the soil. Additional slugs of concrete "seemed" to affect the reading but there was no consistent result and could be more the result of contact effects between slugs of concrete than the contact between the half cell itself and the concrete. Despite the variations, the discrepancies noted in field readings between corresponding concrete and soil measurements could not be duplicated with this laboratory simulation. The effect of the so called "liquid junction potential" could not be detected in this experiment.

The second type of laboratory experiment was set up to determine the effect of pH on the reading. In these experiments, the potential between two copper-copper sulfate reference electrodes was measured. One electrode was placed in Medina tap water which has a pH of 6.5 and the second electrode was in a solution of pH 13. The maximum difference noted was 2 millivolts with the electrode in the alkaline solution positive.

CONCLUSIONS

The results of the field simulation tests lead to the following conclusions:

1 Potential measurements taken with the reference electrode placed on concrete differ from measurements taken with the reference electrode placed in the soil immediately adjacent.

2 There is no consistent pattern to these differences in potential. At some locations, the potential on the concrete is more negative and at other locations (often on the same slab) the reverse is true.

3 Adding water changes the potential measurements in the soil and on the concrete.

4 There is no consistent pattern in the changes resulting from the addition of water. At some locations, the potentials become more negative when water is added and at other locations, the potentials become less negative.

5 The concrete effects noted in the field could not be duplicated in laboratory simulation.

6 Laboratory simulation found no appreciable effect on potential resulting from differences in pH.

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APPENDIX C

GUIDE FOR INSTALLING TEST POINTS

APPENDIX C

GUIDE FOR INSTALLING TEST POINTS

Potential measurements of structures or utilities beneath pavement surfaces should be taken with the half-cell in the soil below the pavement. To take this measurement, drill through the pavement down to the soil, clean out the hole and measure the potential using a copper-copper sulfate half-cell.

PERMANENT TEST POINTS

A permanent test point should be installed for measurements which must be repeated. There are three main variables to choose from when installing test points. These are size of the pavement insert, physical shape of reference electrode, and the type of drill used.

Pavement Insert - The Heath insert has a removable 3/4 inch steel plug and requires a 1-5/8 inch hole at least 5 inches deep for installation. The removable plug should be well tightened before driving it in place with a rubber hammer or block of wood. The Central Plastics insert has the same characteristics except it requires a larger hole (1-3/4 inch by 6 inches).

Reference Electrode - The extended reference electrode (see Figures C-2, C-3) is not commercially available and the wooden end plug is susceptible to rapid clogging. However, the extended reference electrode does permit taking readings to any depth required so a smaller diameter hole can be drilled through to the soil after the appropriate hole for the pavement insert (1-3/4 inch x 6 inches or 1-5/8 inch x 5 inches) has been drilled. Tinker & Rasor and Cathodic Engineering Equipment Company, now sell slim half-cells which can be used with pavement inserts. However, these are only 5 inches long, so the hole must be filled with sand and saturated with water prior to taking potential measurements. This provides a "bridge" to the native soil. The IR drop of this "bridge" can be minimized by drilling the same diameter hole for the insert through to the soil.

Drilling Equipment - Most Air Force bases do not have a rotary-hammer drill capable of drilling a 1-3/4 inch hole. This electric drill is portable and fast but problems may be experienced in removing all debris and drilling fines from the bottom of the hole. Most Air Force bases, though, do have a pneumatic drill powered by a trailer-mounted air compressor. This system is not as flexiable as the electric drill, but it drills just as fast and compressed air can be shot through the drill bit into the hole to thoroughly remove all debris. Both drills are capable of drilling the required hole size in less than 5 minutes in either concrete or asphalt. Special care, though, is required when drilling in asphalt since the drill bit will tend to wobble and enlarge the top portion of the hole. This can be avoided by drilling very slowly until the hole is one inch deep.

TEMPORARY TEST POINT

Where measurements will not be repeated then the hole is simply filled in with cold mix asphalt or cement grout. The asphalt is usually placed into the hole in lifts of 2-1/2 inches and each lift is thoroughly compacted; whereas, the cement grout is simply mixed with water and poured into the hole. The extended half-cell is ideally suited for this application since it can reach the bottom of the hole with the extension through a small 7/8 inch diameter hole. If the smaller, slim half-cells are used then this same size hole must be filled with water or moist sand before a reading can be made or a larger hole (1-1/2 inch) can be drilled and a standard half-cell with PVC extension used.

EQUIPMENT AND MATERIALS REQUIRED

1 Rotary-hammer drill such as Hilti TE60 or pneumatic drill as authorized in TA008, NSN 3820-00-275-2615, Drill Pneumatic Sinker Dry Type, 55 lb.

2 Drill bits as required for type pavement insert used and pavement thickness.

3 Portable motor generator for electric drill and air compressor for pneumatic drill as well as to blow debris from test hole.

4 Plastic Pavement Inserts:

Company:	Central Plastics Co.	Heath Survey Consultants
Size Insert:	1-3/4 inch diameter 6 inch long	1-5/8 inch diameter, 5 inches long
Address:	Post Office Box 762 Shawnee, Ok. 74801 (405) 273-6302	100 Tosea Drive Stoughton, Ma. 02072 (617) 344-1400

5 Patching Materials

Cold Mix Asphalt - Future Patch or equal
21st Century Paving & Construction Materials Co.
P.O. Box 05074
Cleveland, OH 44105
(216) 429-2221

Premixed Cement Grout - Por Rock or equal
Lehn & Fink Industrial Products Division
225 Summit Avenue
Montvale, NJ. 07645

6 Reference Electrodes

Extended Half-Cell - local modification of standard half-cell in accordance with Figures C-2 and C-3.

Test Instruments - The newer electronic instruments have a very high impedance input and are generally more accurate and easier to use than the older analog meters. However, the standard Miller M3M multi-meter authorized for Air Force bases is still an acceptable test instrument when the half-cell is in contact with soil, and the following accomplished:

1 Remove all debris and drilling fines from test hole.
2 Saturate bottom surface of hole with water.
3 Take measurement on different scales to check for high resistance.
4 Take final measurement using the potentiometer PM/VM circuit.

INSTALLATION PROCEDURE

Once you have selected the type pavement insert, reference electrode and drill to use, then the actual installation of each test point can be accomplished in less than eight minutes as follows:

1 Drill the appropriate size hole for the insert either as shown in Figure C-1 or drill the same size hole through to the soil.

2 Thoroughly remove all debris and drilling fines from the hole using compressed air and spoon bits.

3 If the short, slim half-cells are to be used, then fill the hole with clean sand and tamp in place.

4 Thoroughly saturate the bottom surface of the hole with water and take a potential measurement. If reading appears correct then continue installation. If not, then drill deeper, clean out hole and repeat measurement test.

5 Tighten the removable plug on the insert and then drive the insert into the hole using a rubber hammer or a sledge hammer with a block of wood on top of the insert. The top one-half inch of the insert is flared to provide a firm grip in the pavement. If the hole is improperly drilled or sized, then grout the perimeter of the hole with cold mix asphalt such as Future Patch or a premixed cement such as Por Rock before driving the insert.

6 Subsequent measurements after the installation can be taken by removing the steel plug, saturating bottom surface of hole with water and inserting the slim copper-copper sulfate reference electrode.

Slim Half-Cell (1-3/8 inch diameter, 5 inches long) - Two different types are commercially available. One is marketed as a disposable half-cell due to its low cost and generally poor construction. However, it is a usable half-cell for short duration testing. It is available from Cathodic Engineering Equipment Company, P.O. Box 1089, Hattiesburg, MS 39401, (601) 544-7490.

A permanent slim half-cell with a cermic end plug has just recently been marketed by Tinker & Rasor. Specific details on size and quality of materials were not available at this writing, but this half-cell would be the preferred one to purchase. In addition, it may

be possible to add a PVC extension to the top of this slim half-cell. This would give the advantages of the extended half-cell without the disadvantage of the wooden end plug. The disposable half-cell also has a wooden end plug. The permanent half-cell should be available from most corrosion control material suppliers or direct from Tinker & Rasor, 417 Agostino Road, P.O. Box 281, San Gabriel, Ca. 91778, (213) 287-5259.

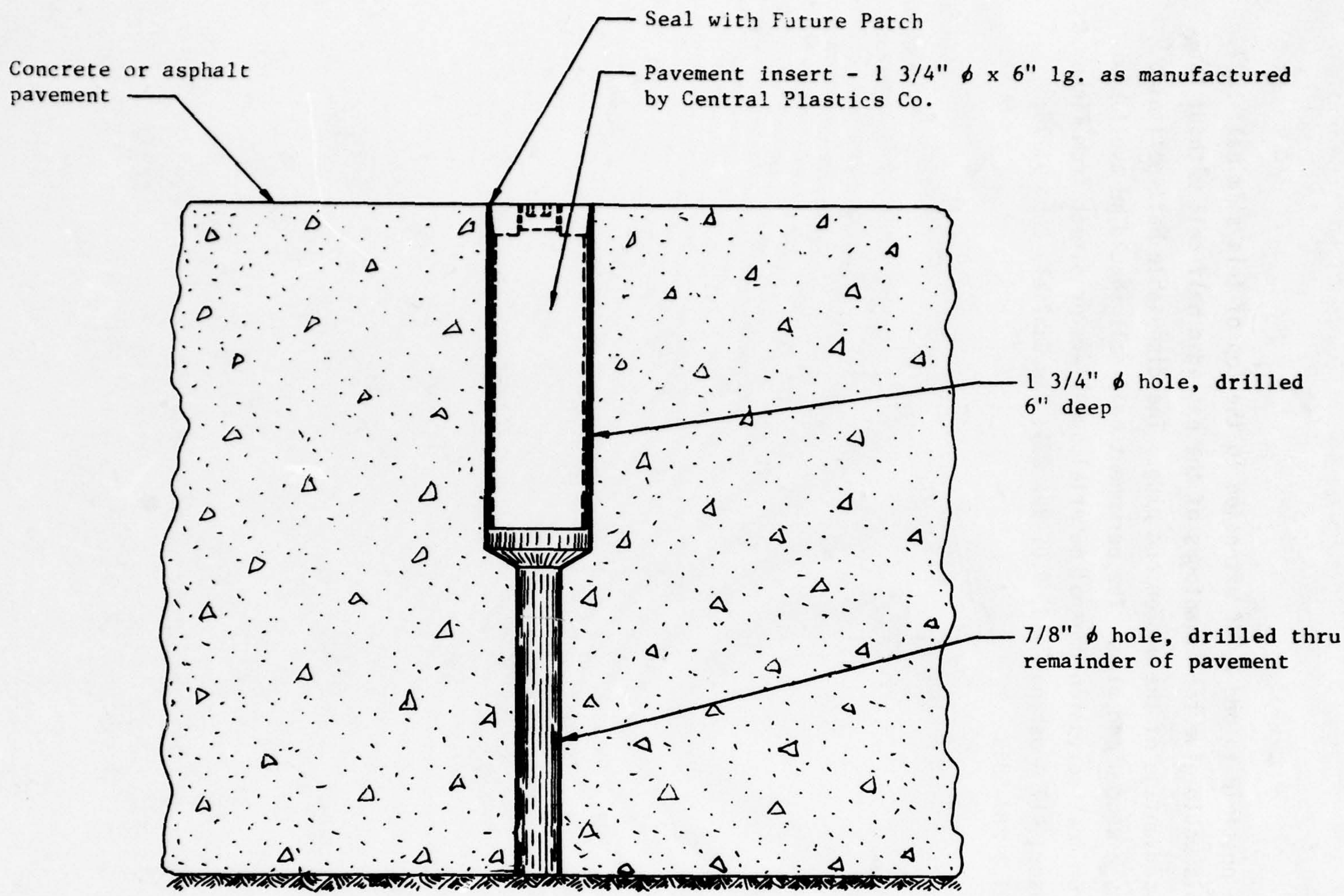


FIGURE C-1 DRILLED TEST HOLE IN PAVEMENT WITH PLASTIC INSERT

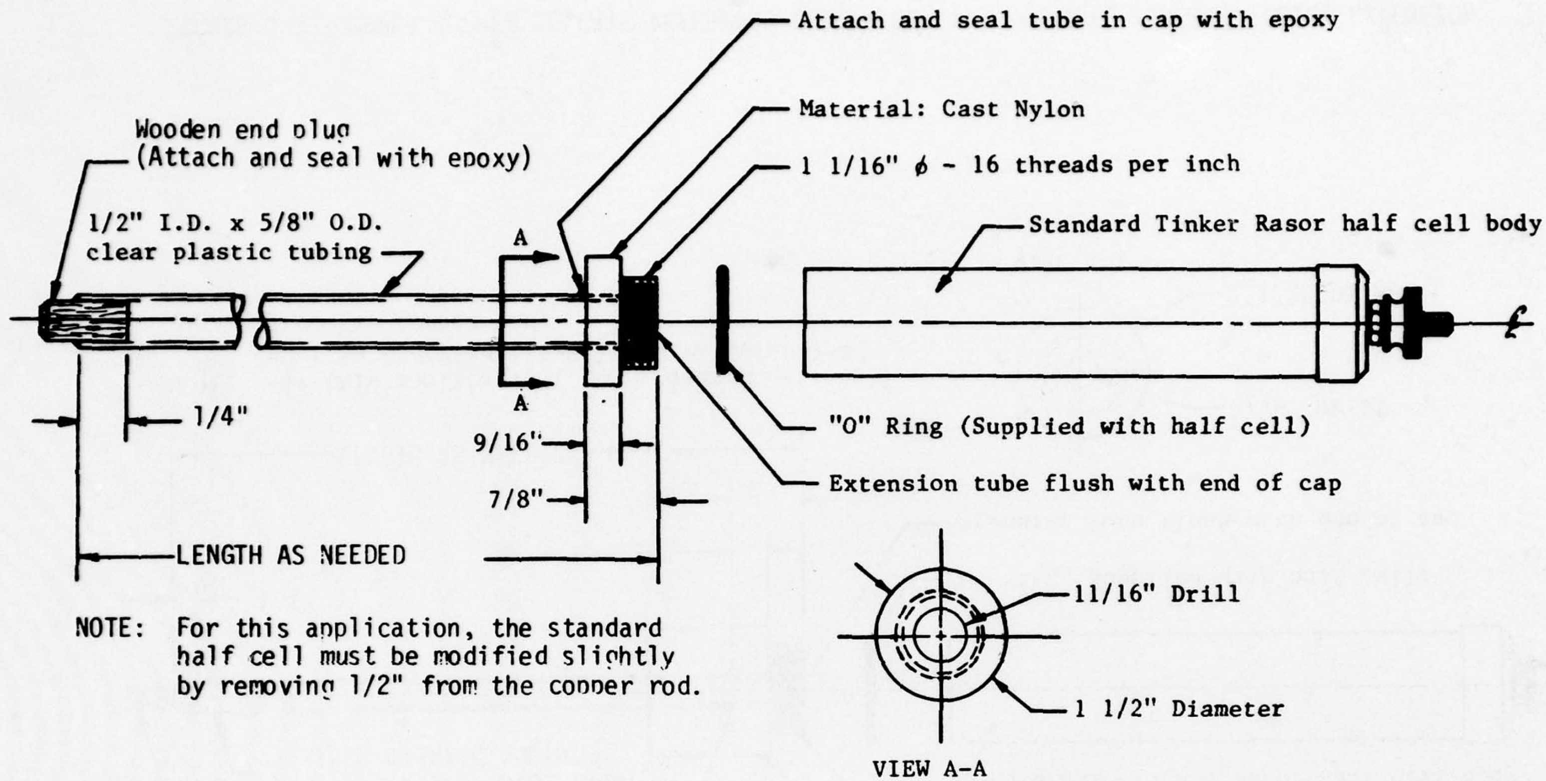
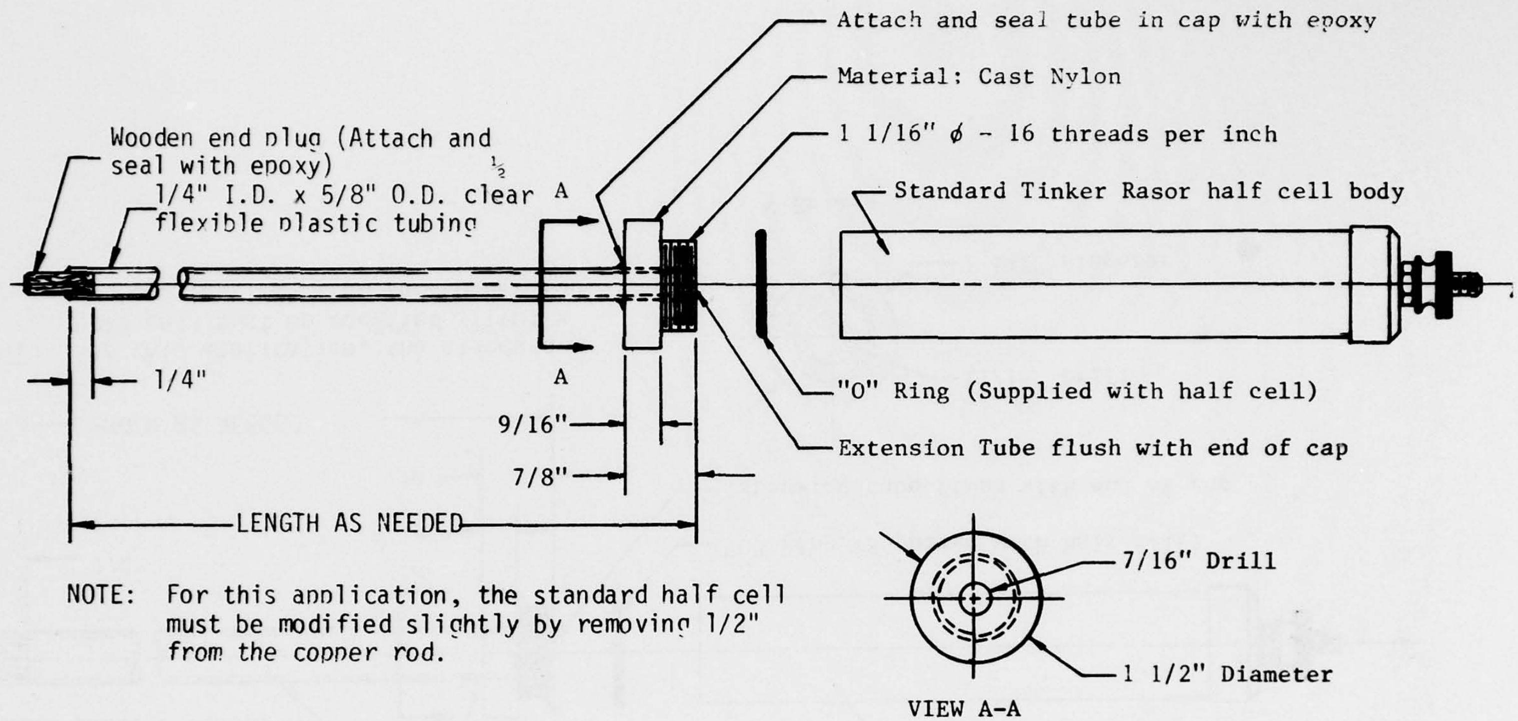


FIGURE C-2 COPPER-COPPER SULFATE REFERENCE ELECTRODE WITH RIGID PLASTIC TUBING EXTENSION



NOTE: For this application, the standard half cell must be modified slightly by removing 1/2" from the copper rod.

FIGURE C-3 COPPER-COPPER SULFATE REFERENCE ELECTRODE WITH FLEXIBLE PLASTIC TUBING EXTENSION

APPENDIX D

COMPARISON ON INSTRUMENT CHARACTERISTICS

INSTRUMENT	ADVANTAGES	LIMITATIONS
Aardvark PEC-VM	Extremely high impedance 1,000,000 megohms Direct reading on analog movement.	Presently a laboratory type instrument. No scale change feature to use to test for high resistance contact. Sensitive to spurious signals.
Miller Model H	Made for field use Change in input resistance makes it possible to determine presence of high resistance contact.	Calculated potential can differ substantially from actual potential.*
Nilsson Model 540	Made for field use. Self-balancing potentiometer makes it possible to determine presence of high resistance contact. Second only to Aardvark in obtaining reading.	Slow action self-balancing potentiometer circuit in situation of very high contact resistance.
Danameter	Some valid readings possible where 10 megohms is adequate.	No scale change feature to use to test for high resistance contact. Digital readings sometimes unstable.

*The formula used for this calculation is inherently susceptible to error. Because the demoninator is equal to the difference of two values, small variations in each of the two values can result in a substantial effect on the final result.

INITIAL DISTRIBUTION

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HQ PACAF/DEMU	2
HQ SAC/DEMH	2
HQ TAC/DEMU	2
HQ USAFE/DEEO	2
HQ USAFSS/DEMU	2
HQ AFRES/DEMM	2
HQ USAFA/DEVCT	2
AFRCE-ER/S4	2
AFRCE-WR/PREHW	2
AFRCE-CR/CRNI	2
AFIT/DET	2
HGB/ANG/PSC/DE	2
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HQ AFESC/TST	1
HQ AFESC/RDCS	10
DDC/DDA	2
HQ AUL/LSE 71-249	1
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NBT/DMT-32	2